Naval Postgraduate School
Monterey, California 93943-5138

SUMMARY OF RESEARCH 1995

Interdisciplinary Academic Groups

C3 - Dan C. Boger, Chairman

Electronic Warfare - Fred H. Levien, Chairman

Space Systems - Rudy Panholzer, Chairman

Undersea Warfare - James Eagle, Chairman

Ching-Sang Chiu
Associate Chair for Research

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NAVAL POSTGRADUATE SCHOOL
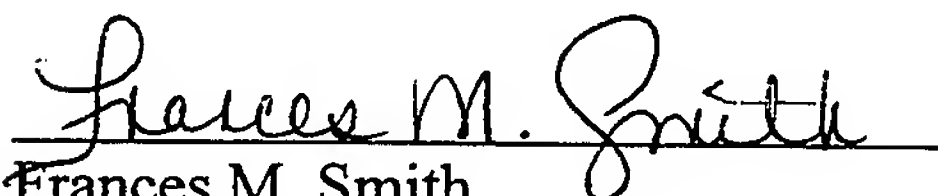### Monterey, California

Rear Admiral M.J. Evans
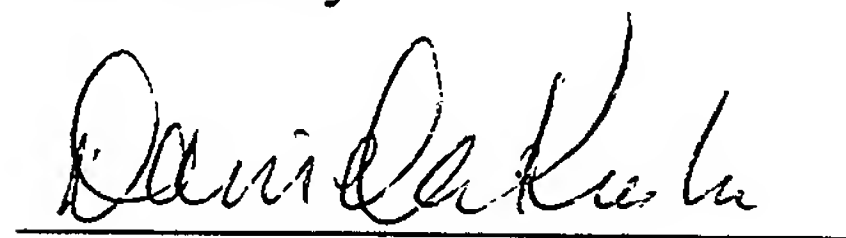Superintendent

R. Elster
Provost

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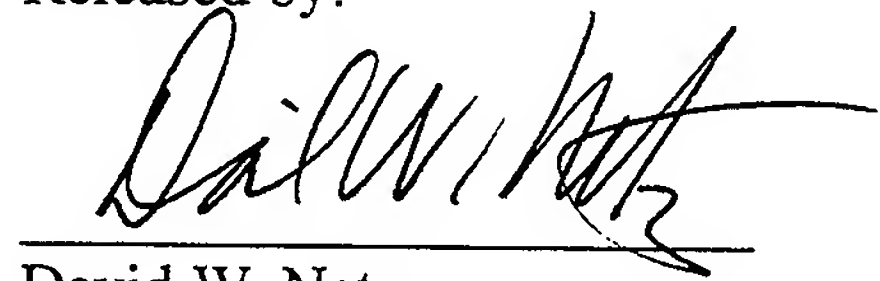
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13. ABSTRACT (Maximum 200 words)

This report contains information of research projects in the four interdisciplinary groups, Command, Control & Communications Academic Group, Electronic Warfare Academic Group, Space Systems Academic Group and Undersea Warfare Academic Group, which were carried out under funding of the Naval Postgraduate School Research Program.

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THE NAVAL POSTGRADUATE SCHOOL MISSION

The mission of the Naval Postgraduate School is to provide advanced professional studies at the graduate level for military officers and defense officials from all services and other nations. The School's focus is to increase the combat effectiveness of the armed forces of the United States by providing quality education which supports the unique needs of the defense establishment.
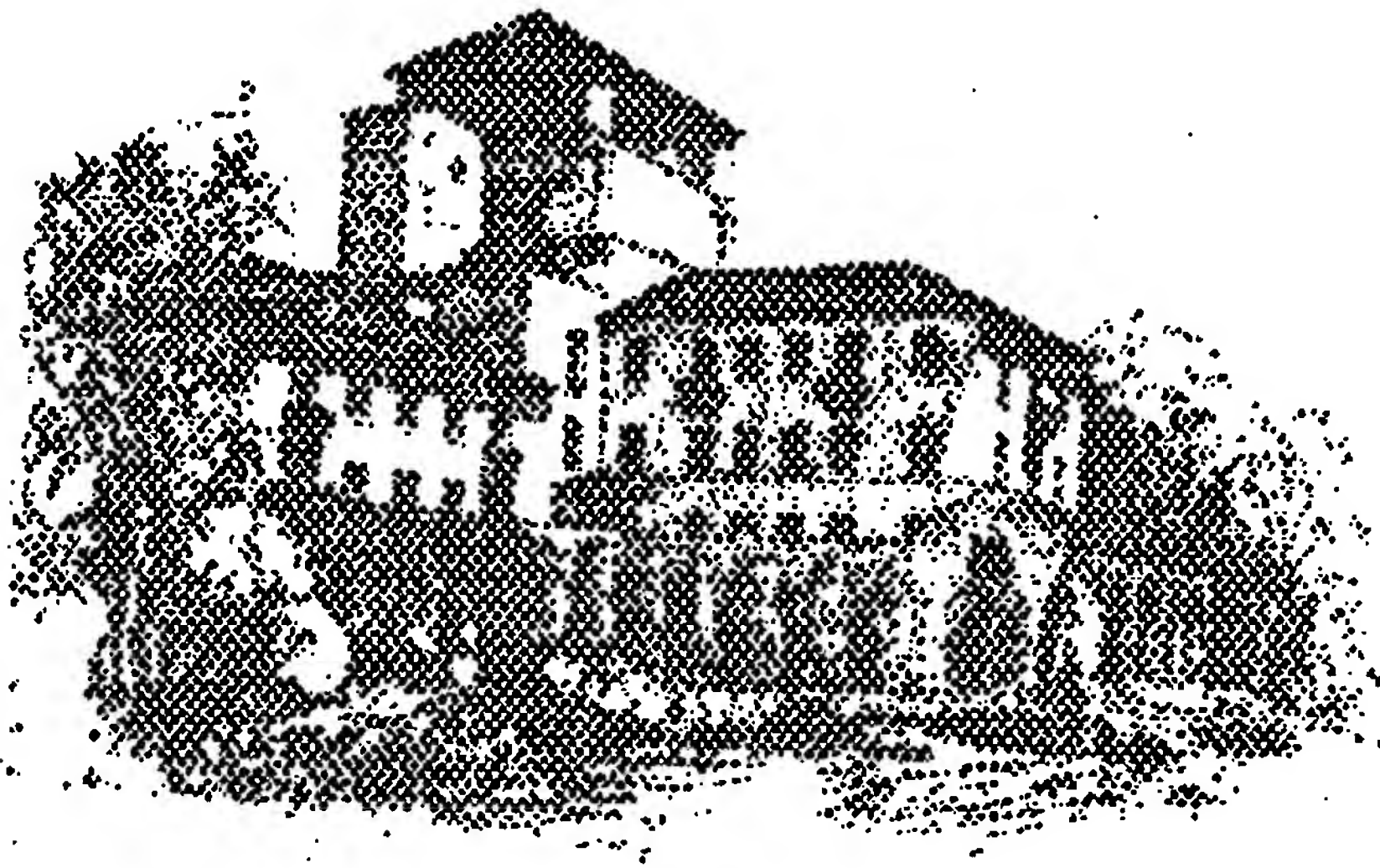
Introduction

Research is an integral part of graduate education. At the Naval Postgraduate School (NPS), the goals of research are to:

- Provide a meaningful, high quality, capstone learning experience for our students.

- Keep faculty on the leading edge of advances in defense-related science, technology, managment and policy to ensure that the latest information is incorporated into NPS courses and curricula.

- Apply faculty and student knowledge to enhance Navy/DoD operational effectiveness.

Pursuit of these goals increases the technical and managerial capability of the officer corps to keep pace with an increasingly complex defense posture in today's world.

The overall research program at NPS has two funded components:

- The Direct Funded Research (DFR) Program provides internal funding from the School's operating budget to stimulate innovative research ideas of benefit to the DoN and may be used for cost-sharing with reimbursable research efforts. This funding ensures, in particular, that all Navy-sponsored NPS curricula are equitably supported, that new faculty are provided an opportunity to establish a research program of importance to DoN/DoD and other national security interests, and that faculty and students from across the campus are encouraged to interact with one another.

- The Reimbursable Research (RR) Program includes those projects externally funded on the basis of proposals submitted to outside sponsors by the School's faculty. These funds allow the faculty to interact closely with RDT&E program managers and high-level policy makers throughout the Navy, DoD, and other government agencies as well as with the private sector in defense-related technologies. This ensures that NPS research remains highly regarded by academic peers and government officials and fosters a closer relationship between NPS and other outside organizations.

The two research programs are complementary and ensure that the overall research program is flexible, responsive, balanced and supportive of the unique needs of the military.

All research projects, both reimbursable and direct funded, support the School's research mission:

- To develop an overall research investment strategy that ensures a high quality, creative learning experience for NPS graduate students.

- To encourage faculty and student pursuit of new discoveries and applications which enhance the long term effectiveness of the armed forces.

- To stimulate interactions between NPS faculty and a wide variety of potential research sponsors (Government, Universities, Private Industry).

- To publicize (both internally and externally) significant achievements of the NPS research program and market NPS research capabilities.

- To foster synergy and force multiplication with Navy/DoD commands and laboratories to increase the potential for successful research and development programs

The Command, Control and Communications Academic Group consists of a small number of full-time C3 faculty plus faculty interested in C3 from the Computer Science, Electrical and Computer Engineering, Meteorology, National Security Affairs, Operations Research, Physics and Systems Management departments. The C3 Academic Group is responsible for the academic content of the Joint C4I Systems (365) curriculum and the Scientific and Technical Intelligence (823) curriculum. In carrying out this responsibility, the C3 Academic Group monitors courses taught in other departments in the areas of Communications and Sensors, Operations Analysis, and Computer and Information Systems. The C3 faculty guide the students in their thesis projects and conduct research in the support of C3 systems, C3 modeling, and C3 policy.

The Electronic Warfare Academic Group* consists of faculty from the Electronic Warfare department plus interdisciplinary faculty from Physics, Operations Research, Electrical and Computer Engineering, Mathematics, Computer Science, Systems Management, C4I, and Joint Warfare. There is in addition a military officer from three services, Army, Navy and Air Force in the Group. The group direct theses in all aspects of electronic warfare.

The Space Systems Academic Group (SSAG) is an interdisciplinary association providing direction and guidance for graduate-level instruction in Space Systems Engineering and Space Systems Operations. In addition to a small number of full-time faculty, the SSAG relies on faculty and facilities support from the Departments of Aeronautics and Astronautics, Computer Science, Electrical and Computer Engineering, Mathematics, Mechanical Engineering, Meteorology, Oceanography, Operations Research, Physics, and Systems Management. In developing this expertise and providing support to student theses, the group has built a military satellite laboratory.

The Undersea Warfare (USW) Academic Group consists of an interdisciplinary group of faculty from Operations Research, Oceanography, Electrical and Computer Engineering, Mathematics, and Physics departments. The USW faculty provide graduate level instruction in antisubmarine warfare, submarine warfare, mine warfare, torpedo defense, and acoustic surveillance. The USW academic group also monitors all USW-related research conducted at NPS.

* Electronic Warfare Academic Group name changes to Information Warfare Academic Group in 1996.

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COMMAND, CONTROL AND COMMUNICATIONS (C3)

The Command, Control, and Communications (C3) Academic Group is an interdisciplinary association of faculty which consists of 18 faculty members who hold appointments in eight departments at the Naval Postgraduate School, plus the Curricular Officer. The C3 Academic Group has responsibility for the academic content of the Joint Command, Control, Communications, Computers, and Intelligence Systems Curriculum and the Scientific and Technical Intelligence Curriculum. C3 Academic Group faculty members carry out research in C4I systems to support these two curricula.

During 1995, the C3 Academic Group consisted of the following members:

> Lieutenant Colonel Ernest K. Beran, USAF (39), Curricular Officer
> Professor Dan C. Boger (SM), Chairman
> Associate Professor Ralph N. Channel (NS)
> Professor Kenneth L. Davidson (MR)
> Professor Donald P. Gaver (OR)
> Major John Gibson, USAF (C3)
> Associate Professor Wayne P. Hughes (OR)
> Commander Peter Hull, USN (NS)
> Professor Carl R. Jones (SM)
> Assistant Professor William G. Kemple (C3)
> Professor Herschel H. Loomis (EC)
> Associate Professor Paul H. Moose (EC)
> Visiting Associate Professor Orin E. Marvel (C3)
> Associate Professor John S. Osmundson (C3)
> Assistant Professor Craig Rasmussen (MA)
> Lieutenant Commander Michael Shields, USN (EC)
> Assistant Professor Timothy J. Shimeall (CS)
> Professor Michael G. Sovereign (C3)
> Associate Professor Donald V.Z. Wadsworth (EC)

An overview of the Command, Control, and Communications (C3) Academic Group research program follows.

Adaptive Architectures for Command and Control

Professors **Michael Sovereign** and **William Kemple** began a four-year, continuing project whose objectives are to: extend twelve years of Navy decision-making research into the joint C2 arena; expand the domain beyond the frequently studied anti-air warfare arena; focus on adaptive architectures; and produce results ranging from purely theoretical to those that can be used by the operational forces in the near term. This project is the NPS portion of a government, industry, academic team formed by Office of Naval Research to carry out this program.

Systems Engineering of Networked, Distributed Systems

Professor **John Osmundson** began a project whose objective is to develop analytical, and modeling and simulation techniques for the analysis, design, rapid prototyping, and tradeoff studies of complex, time-critical, and networked distributed systems. This project is a two-year effort which began in January 1995 and will end in December 1996.

Common Data Link (CDL) Interfaces to the Global Network Architecture

Professors **Paul Moose**, Shridhar Shukla (EC), and Gilbert Lundy (CS) continued their research into emerging high speed networking architectures and protocols for design of a seamless interface of the CDL to the global broadband network. The first goal is to use these architectures and protocols to develop a CDL-network interface for both ends

of the data link. A ranking methodology based on a set of evaluation metrics is being developed and will be applied to the different alternatives identified. The second goal is to develop an implementation plan for integrating CDL into the DoD global network architecture. The plan being developed includes a verification of the integration concept along with assessments of protocol availability, interoperability, network management issues, and performance-related modeling and tradeoffs.

Alternative Concepts of Operation for Direct Downlink of Sensor Information

Professors **Dan Boger** and **Carl Jones** continued their research into the potential benefits to the Joint Task Force Commander for real-time command and control of warfighting forces through the direct downlinking of information from sensors. By examining specific JTF-level scenarios, several alternative concepts of operation for directly-linked sensor information are being compared to current, existing sensor information architectures. Measures of effectiveness focus on the tradeoff of latency for quality of information. Scenarios involving both generic command and control as well as targeting-quality information for specific weapons systems are being evaluated.

Support for Tactical Decision Making Under Stress Experiments and Data Analysis

Professor **Michael Sovereign** and Research Psychologist Susan Hutchins continued research support to the Tactical Decision Making Under Stress (TADMUS) Program, sponsored by ONR. The objective of the TADMUS program is to apply recent developments in decision theory, individual and team training, and information display to the problem of enhancing tactical decision quality under conditions of stress. The specific research support in this project is being provided to NRaD, where the experiments are being conducted, and this support includes a decision support system, training strategies, and alternative human-machine interface concepts. Experimentation using specific anti-air scenarios is used to assess the effectiveness of the newly developed decision support system.

Support for the Joint C4I Chair Professorship

Professor **Orin Marvel**, the holder of the Joint C4I Chair Professorship sponsored by the Defense Information Systems Agency, continued his research in systems engineering for C4I systems and theater missile defense. He also continued his support of the Joint C4I Systems curriculum through further development of systems engineering projects and courses.

FY95 REIMBURSABLE PROGRAM
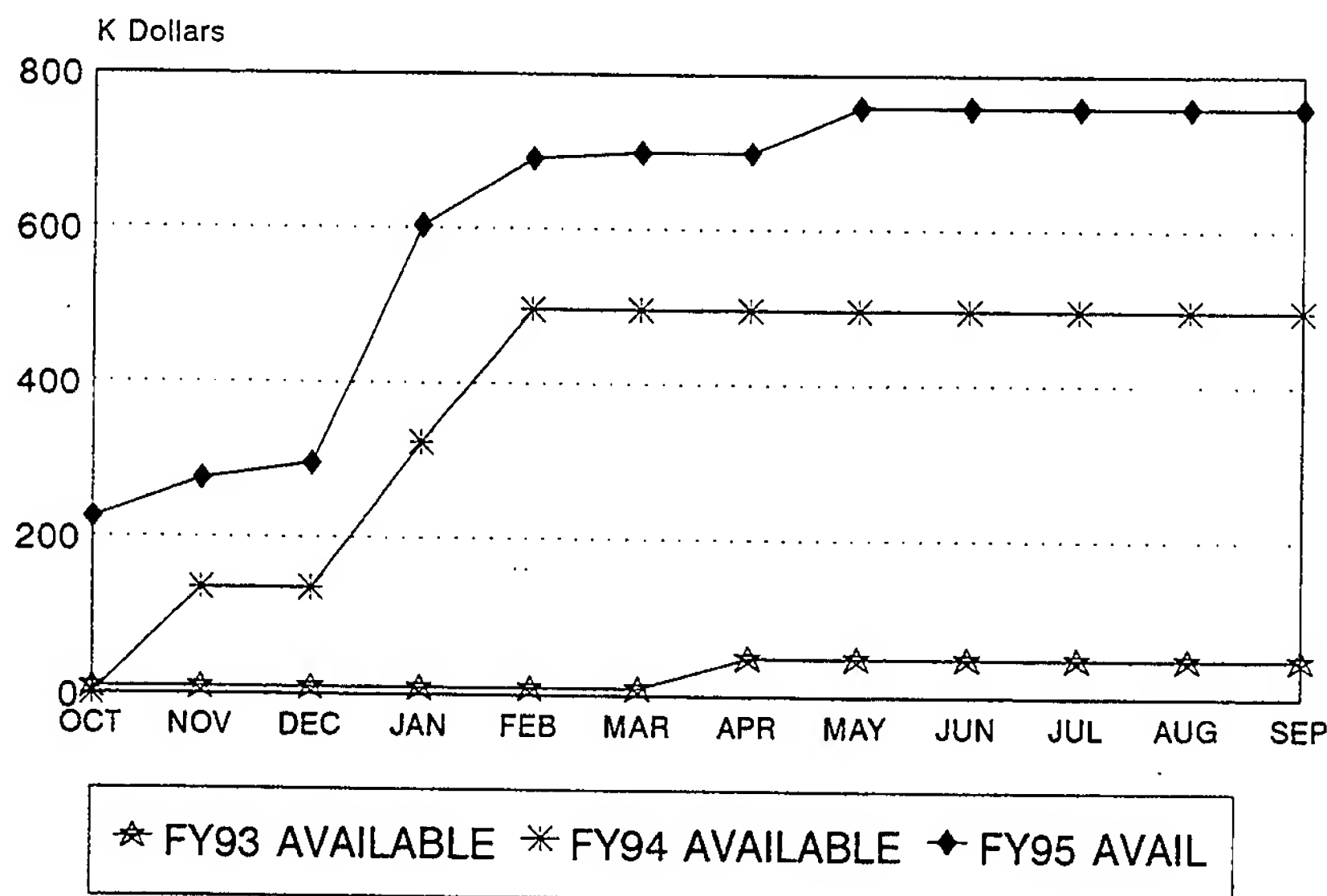## C3 Academic Group

K Dollars

Figure 1. Reimbursable Funds Available by Fiscal Year.
This graph shows the amount of reimbursable funding available to the department. Dollar amounts include research and academic reimbursable activities.
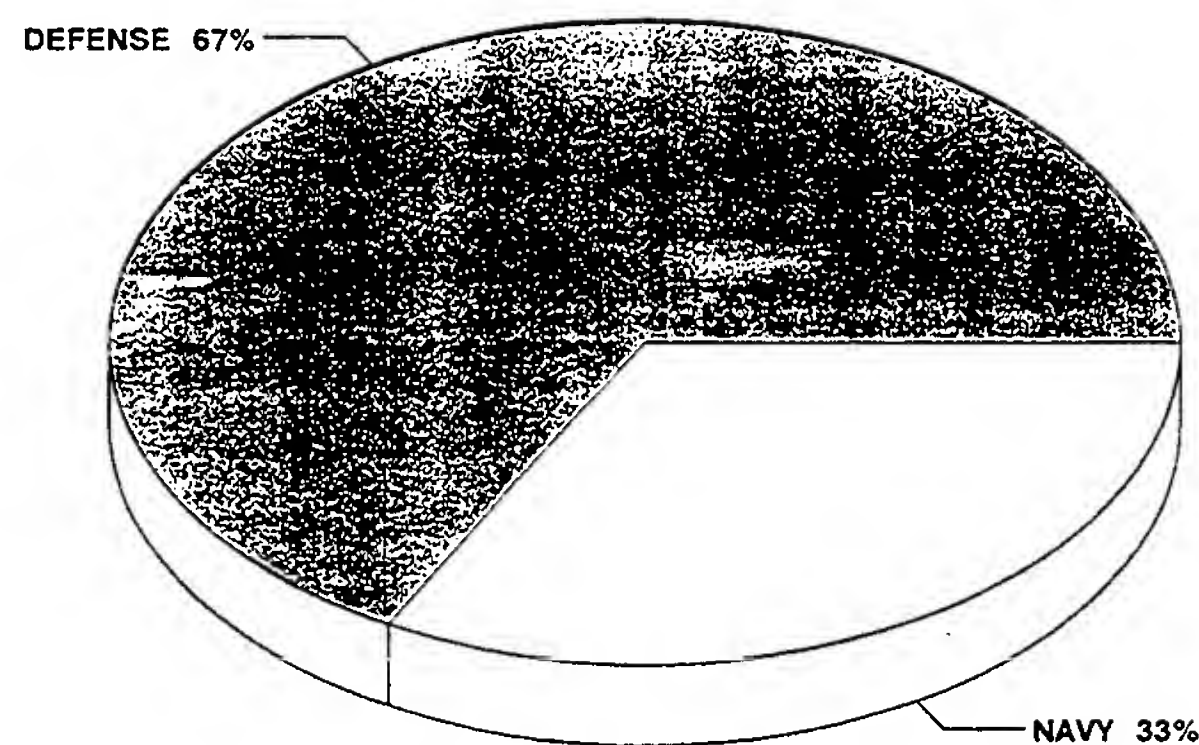

Figure 2. FY95 Reimbursable Sponsor Profile.

ELECTRONIC WARFARE
ACADEMIC GROUP

ELECTRONIC WARFARE

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ELECTRONIC WARFARE*

The Electronic Warfare Academic Group (EWAG) is an interdisciplinary group of faculty who hold appointments in various departments at the Naval Postgraduate School. These faculty members are responsible for guidance of the Electronic Warfare Curriculum for U.S. and International students. Their participation in the EWAG is voluntary and is a result of their interest in applying expertise to problems related to electronic combat.

Most EWAG faculty do some research related to electronic warfare. The primary purpose of this summary is to provide an overview of their work. In addition, there are a few faculty members who do EW research and who are not currently EWAG members. They are included here as well in order to provide a comprehensive overview of NPS faculty participation in support of electronic warfare.

The individual research summaries and publication lists of the EWAG faculty are not included in this section. Since all EWAG faculty hold appointments in their own department, their summaries and publications appear there.

During 1995, the membership of the Electronic Warfare Academic Group was as follows:

Professor Frederic H. Levien (EC), Chairman
Commander Robert Young, USN (37), Curricular Officer

Associate Professor Mike Bailey (OR)
Lieutenant Colonel Ernest K. Beran, USAF (39), Curricular Officer
Assistant Professor Mitch Brown (NS)
Professor Alf Cooper (PH)
Professor Ken Davidson (MR)
Associate Professor Wayne Hughes (OR)
Associate Professor Dave Jenn (EC)
Professor Jeff Knorr (EC)
Professor Mike Morgan (EC)
Associate Professor Phil Pace (EC)
Professor Kurt Schleher (EW)
Associate Professor Don Wadsworth (EC)

The following personnel, although not members of the 1995 EWAG, had research programs which contributed to the success of the electronic warfare program:

Associate Professor Richard Adler (EC)
Associate Professor Gurnam Gill (EC)
Associate Professor Robert Hutchins (EC)
Associate Professor Ramakrishna Janaswamy (EC)
Professor Chin-Hwa Lee (EC)
Associate Professor Ron Pieper (EC)
Professor Clark Robertson (EC)

An overview of the Electronic Warfare Academic Group research program follows below:

Aerodynamic Radar and EW Radomes

Several improvements to existing radome computer code have been developed by **Professor Jenn**. They include multilayer radome materials allowing for arbitrary antenna excitation functions, and computing the ohmic loss and its effect on gain. HARM radome scattering was measured in the remodeled NPS anechoic chamber and the data compared to the code results.

ELECTRONIC WARFARE*

Assessing the Effectiveness of Shipboard Countermeasures

A new class of algorithms and modeling techniques that correlate the different hardware-in-the-loop threat simulator test configurations have been developed by **Professor Pace**. These techniques allow a single measure of ECM effectiveness to be calculated numerically across all experimental configurations with a high degree of confidence. Improving this evaluation process is helping to reduce the number of required captive-carry field tests.

Atmospheric Electro-magnetic/Electro-optic (EM/EO) Sensors

A study to provide the capability to make meteorological measurements to appropriate type, accuracy, and time-frequency to support assessment of EM and EO propagation conditions by small combatants in coastal and littoral regions was undertaken by **Professor Davidson**.

Calibration Required Indicator

An investigation into the possible methods of calibrating shipboard high frequency direction finding systems is being conducted by **Professor Jenn**. A complete calibration requires days of at-sea time and there is currently no firm indicator of whether there is a need to calibrate after a topside configuration change.

Coastal Region Refractive Assessments

This analysis and interpretation of atmospheric surface and mixed-layer data collected in "at sea" experiments is being conducted by **Professor Davidson**. The analysis will be relative to models and approaches being considered in present and future EM programs for the coastal region.

Communications Vulnerability to Jamming

Efforts are underway to develop models for assessing the vulnerability of radion frequency tactical communications systems to both conventional and smart jamming attack by **Professor Wadsworth**.

Direct Digitization and Optical Telemetry of Antenna Signals

This research by **Professor Pace** is to investigate the feasibility of directly digitizing wideband direction finding antenna signals using high-resolution symmetrical number system techniques.

Distributed Electronics Counter-Measures (ECM)

Preliminary investigations were conducted by **Professor Schleher** to assess the viability of the synergistic use of individual ECM systems to effectively magnify the effective radiated power (ERP) of distributed ECM assets.

Dual Baseline Triangulation

A new method for IR passive ranging based on the principle of triangulation has been considered by **Professor Pieper and Professor Cooper**. The proposed orthogonal dual baseline scheme eliminates the well known geometric dilution effect, inherent in single baseline methods. The performance of each of the two orthogonal baselines depends on target

orientation and limitations in the precision in the bearing measurements. A general expression, involving both baselines, for the maximum triangulation range is derived as a function of a polar angle measured relative.to the center of the dual baseline system. Limitations in the dual baseline model due to the geometrically assessed optical horizon are also considered.

Electronic Surveillance

A simulation is being created by **Professor Knorr** using computational electromagnetic software, signal processing software and display software for visualization and interpretation of results. This project was initiated during the third quarter of FY 94 and there are no results to report at this time.

Extraction of Threat Critical Parameters

A modular software executive has been constructed by **Professor Pace** to read anti-ship cruise missiles (ASCM) simulator CTS characterization test files, extract the threat critical parameters and directly compare the results with the Electronic Warfare Integrated Reprogrammable (EWIR) database. The difference between the simulator parameter value and the EWIR value for each critical parameter is used to generate an impact statement which informs the operational test community of any situation that might be affected by this parameter difference. These results are an integral part of the SVWGs validation report for each ASCM simulator.

Frequency-Hopped Systems over Fading Channels

The performance of various M-ary orthogonal, noncoherent frequency-shift keying communication systems employing fast frequency-hopped spread spectrum waveforms transmitted over a frequency-nonselective, slowly fading channel with partial-ban interference have been analyzed by **Professor Robertson**.

Low Probability of Intercept Radar

Performance of Crystal Video and IFM receiver based electronic support measure (ESM) systems against LPI radar waveforms were modeled by **Professor Schleher**. The response of the SLQ-32 ESM system to LPI radar waveforms was determined experimentally. Experimental and modeled responses are in good agreement.

Missile Closure Simulation

Naval Air Warfare Center - Weapons Division is undertaking a study with **Professor Hutchins** of simulation methodologies to support testing of missile approach warning systems (MAWS) without live missile firings. The actual missile sensor is to remain mounted on the ground, where it can receive illumination from the aircraft. This study will address a characterization of end-game behavior, missile dynamic simulation for virtual fly-out, actual real-time observations from the ground-mounted missile seeker, real-time modifications to the actual measurements to account for higher signal strength as aircraft range and orientation change during the virtual encounter, real-time modifications to the actual measurements to account for background clutter at the appropriate relative Doppler during the virtual encounter, and methods and concepts for obtaining test data sets to assist in the above real-time measurement modifications.

Optimum Probability of Kill for Surface Ships

The characteristics of the SLQ-32 for softkill and the SM-2 missile for hardkill are combined with other last-ditch defense systems by **Professor Levien** to determine which combinations of a coordinated ship's defense offer the Commanding Officer the optimal approach to defend the ship. A computer simulation algorithm is incorporated into the study which yield a final probability of kill for various combinations of defense.

Performance Evaluation of Ground Based Radar

Ground based radar systems are a critical resource to C4I system performance. The thesis provides the tools and methods for a better understanding of the actual performance of a ground based radar system. A mulitpath study was performed by **Professor Levien** and coverage diagrams generated. Atmospheric data was used with IREPS and EREPS software to illustrate the impact of atmosphere on the radar system's performance.

Periscope Detection Radar

An advance simulation model was developed by **Professor Schleher** which allows the performance of periscope detection radars to be determined. An advanced periscope detection radar was synthesized and analyzed. Performance curves which show the performance of this type of radar as a function of radar resolution and altitude was generated.

Radar Cross Section Synthesis

In the design of a stealthy vehicle, it is desirable to have a mathematical procedure for obtaining its surface material electrical characteristics from a specified radar cross section (RCS). A synthesis procedure has been developed by **Professor Jenn** to determine the material properties of an arbitrary target so that a specified radar cross section is obtained.

Radar Cross Section Reduction

The RCS reduction of indirect-fire projectiles has been demonstrated by **Professor Jenn** using an electromagnetic simulation code. Significant reduction was achieved by simply adding two shallow slots to the round. Future research will investigate the effectiveness of other parasitic elements in reducing RCS.

Radiowave Propagation in a Duct

The Parabolic Equation (PE) method has emerged as an extremely valuable method for assessing radiowave propagation in the lower atmosphere in the presence of ducts. Propagation loss can be easily estimated over very long ranges of the order of a few hundred kilometers for frequencies through Super High Frequency (SHF) band, and for antenna heights extending up to a few hundred meters. It is also possible to directly account for finite conductivity of the earth in the PE. Although there are many different ways of solving the PE, none seem to offer the computational advantages of the split-step algorithm being investigated by **Professor Janaswamy**.

Radar Signature Cancellation

Implementation approaches and combat effectiveness for a powerful new radar signature cancellation approach are being analyzed for use on military platforms by **Professor Morgan**. The technique employs distributed active canceler

modules to achieve deep signature reduction in all directions, even against future bistatic radars and impulse radars. This approach can be applied to air and ground vehicles, fixed installations, as well as surface ship combatants. Analysis is being conducted through modeling and simulation of the combat effectiveness of radar signature reduction vs. frequency range for number and placement of canceler modules on tactical aircraft in selected engagement scenarios.

Synthesis of Radar Cross Section

RCS synthesis formulas were derived by **Professor Jenn** for the general problem of a target of known shape with a plane wave incident. Two approaches were considered. The first was rigorous, and required solving for both the current and surface impedance of the body. The second was an approximate approach whereby the current was estimated and only the surface impedance determined. The synthesis equations were verified using a thin resistive strip as the target.

Superresolution Imaging of Radar Targets

In normal radar cross-range resolution is proportional to real antenna beam width and range to the spot to be mapped. Superresolution techniques increase the resolution by additional signal processing instead of stretching the radar parameters. Recent developments by **Professor Gill** in spectral analysis promise improved frequency resolution and other improvements.

Surface Mode Processing for Target Detection

Trade-offs in performance versus hardware complexity were evaluated by **Professor Pace** for two search processor configuration for several slow moving targets of various size buried in recorded sea clutter data. A retrofit of the current Phalanx hardware to perform this search/detection processing was studied and an optimal inverse filter was constructed that could be implemented in the currently configured hardware.

Ultra-Wideband Impulse

Tests were performed by **Professor Levien** using gallium arsenide bulk devices as impulse sources on an operating SLQ-32 and three operating radar systems, SPS-12, SPS-58A, and SPS-65. Additional exposure to three other EW systems was also conducted.

Verification of Marine Aerosol Models

Aerosol models are being evaluated/formulated by **Professor Davidson** on the basis of analyses and interpretation of measurements of near-surface influencing factors.

Verification of the Radar Range Equation

It was demonstrated by **Professor Levien** that simulation results using the basic IMOM radar range equation adaptations agreed with radar theory. In addition, the manner in which the radar range equation was modified by IMOM to account for stand-off jamming effects was also reviewed. Typical operational values were substituted into these equations and results compared to those calculated by IMOM.

ELECTRONIC WARFARE*

Signal to Noise Enhancement

Development of techniques and methodology for identifying and locating radio noise sources at Naval Security Group (NSG) sites worldwide was continued by **Professor Adler**. The Automated Performance Evaluation Technique for HF receiving sites was simplified and improved. Support was provided to NSG via review of pre-survey planning documentation, mitigation plans and authoring "Quick-Look" and final site-survey reports. Students and NSG site personnel were trained as part of the NSG support. A standard was proposed for limits on the EMI/RFI current allowed in Navy SIGINT sites. Mitigation studies for eliminating interference to receiving equipment from electronic switching systems were successful. Two examples of this were presented in student theses. A two and one-half day HF Technical Review of Factors that Affect Performance of Naval Receiving Sites was hosted for CNSG.

Field Station Research

The Army's Field Station KOREA Tactical SIGINT sites at the three DMZ detachments received a thorough site performance investigation from **Professor Adler**. A new site being developed at Ft. Gordon was suspect in terms of its suitability as a SIGINT operation center. NPS used techniques developed for the Naval Security Group HFDF sites to assess the state of performance and identify factors that degraded performance. Recommendations for mitigation of noise sources which were located was made.

High Latitude Propagation Research

Numerical models of commercial and NPS-built HF receiving antennas were developed by **Professor Adler** and used to provide gain values for ionospheric field strength models. Selected HF ionospheric propagation prediction codes were evaluated and compared to measured data for polar regions. A Doppler shift and spread study was initiated to establish parameters needed to characterize the polar ionospheric regions.

Active Phased Array Radar

The first deployment of Active Phased Array Radar (APAR) was in the USAF Advanced Tactical Fighter (ATF). Westinghouse and Texas Instruments (TI) formed a joint venture for the development of APAR systems. Flight tests were done in 1990 to 1991. A full scale development model was scheduled for late 1993. Since the middle of the 1980s, foreign countries have initiated numerous programs to develop future APAR systems. There will be increasing threats of adversary forces using APAR systems in the future. The purpose of this study by **Professor Lee** is to analyze the ongoing development efforts and reveal the system parameters and the anticipated system performance.

* NOTE: Information Warfare Academic Group to replace Electronic Warfare Academic Group in 1996.

FY95 REIMBURSABLE PROGRAM
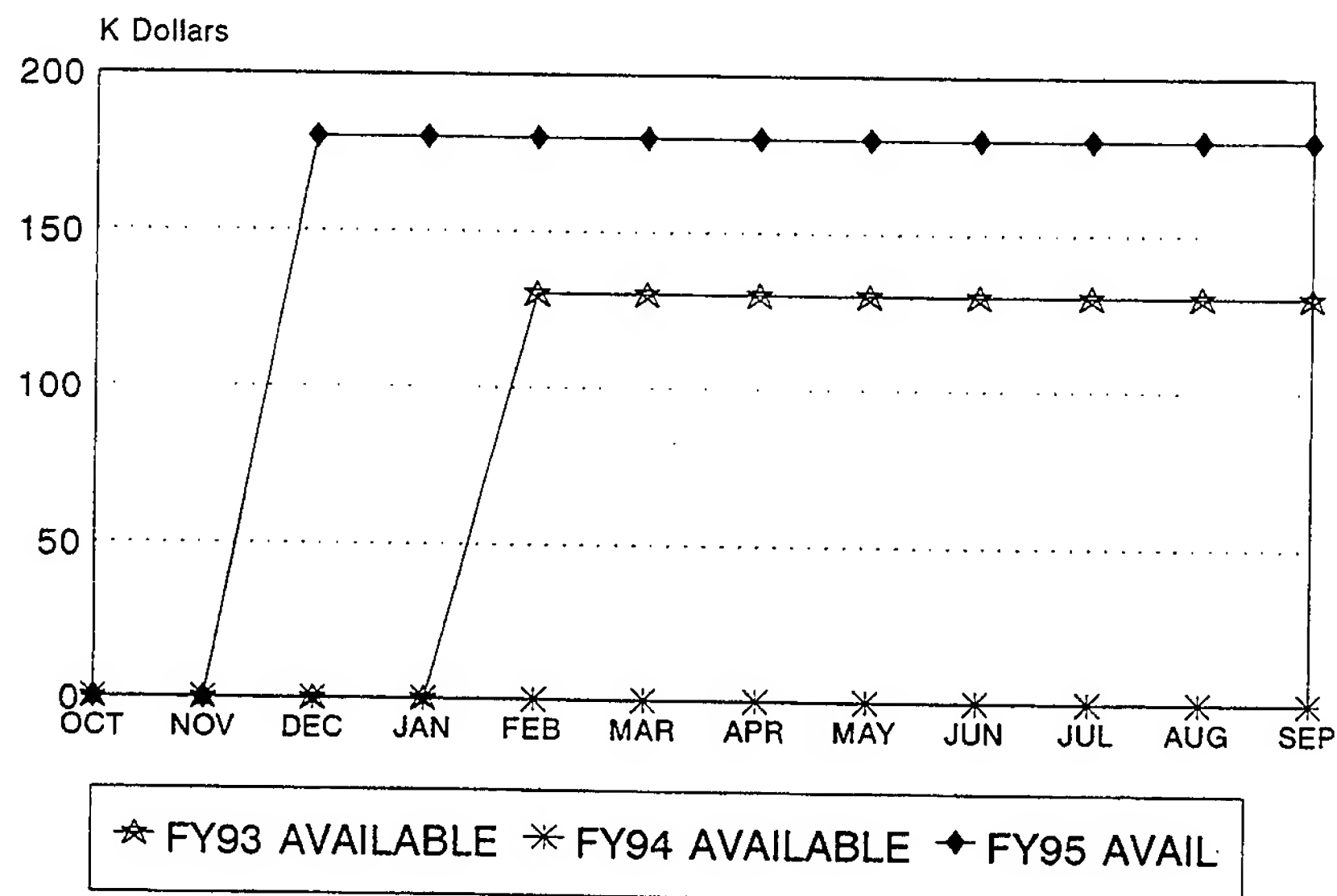## Electronic Warfare Academic Group

K Dollars

Figure 1. Reimbursable Funds Available by Fiscal Year.
This graph shows the amount of reimbursable funding available to the
department. Dollar amounts include research and academic reimbursable
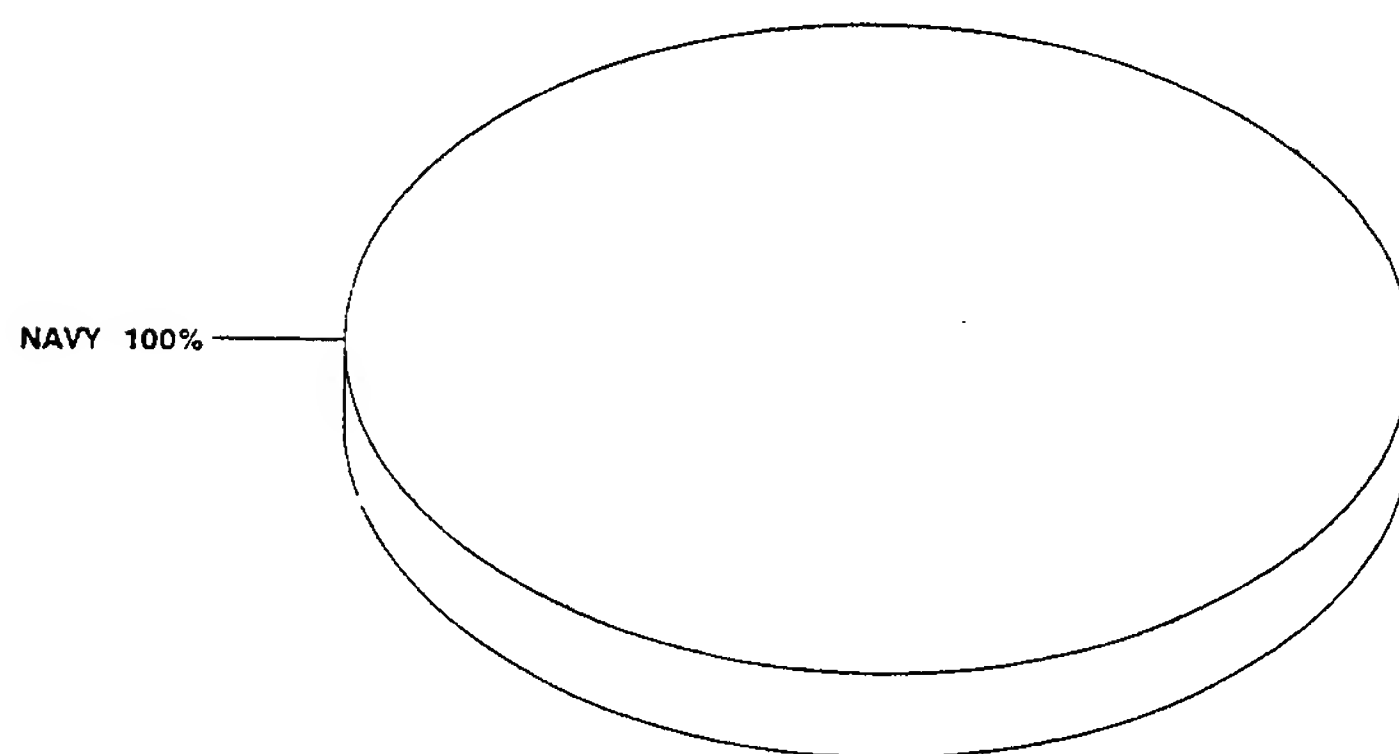activities.

Figure 2. FY95 Reimbursable Sponsor Profile.

SPACE SYSTEMS
ACADEMIC GROUP

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SPACE SYSTEMS

The Space Systems Academic Group (SSAG) is an interdisciplinary association providing direction and guidance for the Space Systems Engineering and Space Systems Operations curricula. The SSAG relies on faculty and facilities support from the departments of Aeronautics and Astronautics, Computer Science, Electrical and Computer Engineering, Mathematics, Mechanical Engineering, Meteorology, Oceanography, Operations Research, Physics, and Systems Management. The SSAG also benefits from the support of four Academic Space Chairs: Navy TENCAP Space Chair, Naval Space Technology Program Chair, Navy Space Systems Academic Chair, and Michael J. Smith Space Systems Chair.

The mission of the SSAG is to provide space systems officer students practical learning opportunities via hardware-based theses and experience tours to supply our sponsors with adequate numbers of space-qualified military personnel; and to develop the Naval Postgraduate School's Space Systems Engineering and Space Systems Operations academic curricula programs.

Ongoing projects within the SSAG provide a space-hardware-oriented environment ideal for students to gain experience in design, development, installation, system integration, and maintenance of spacecraft and payloads. Officer students are exposed to space related research projects as well as formal classroom instruction, and are required to complete a space-oriented thesis for the Master of Science degree.

In the 1995 academic year, officer students in the Space Systems Curricula and participating faculty from several departments were engaged in six major areas of space research and development: (1) Spacecraft Technology--Small Satellite Design Studies; (2) Satellite Communications; (3) Remote Sensing; (4) Space Warfare, and; (5) Computer Memory Technology in Space. In addition, (6) SSAG assisted participating departments in the continuing development of several Spacecraft and Flight Hardware Laboratories and Support Facilities.

1995 SSAG membership includes:

Professor Rudolf Panholzer (EC), Chairman
Professor Brig Agrawal (AA)
Terry Alfriend (SP), TENCAP Space Chair
Tom Betterton (SP), Technical Chair
Professor Oscar Biblarz (AA)
Professor Dan Boger (SM)
Associate Professor David Cleary (PH)
Lieutenant Commander Bill Clifton, USN (SP)
Professor Donald Danielson (MA)
Professor James Eagle (UW)
Lieutenant Commander D. Farley, USN
Assistant Professor Douglas Fouts (EC)
Vicente Garcia (EC)
Professor Sunthara Gnanalingam (PH)
Jeff Jenner (SP), Michael J. Smith Space Systems Chair
Professor Carl R. Jones (SM)
Visiting Assistant Professor Barry Leonard (AA), Naval Space Systems Academic Chair
Professor Herschel H. Loomis (EC)
Associate Professor Sherif Michael (EC)
Professor Conrad Newberry (AA)
Associate Professor Chris Olsen (PH)
Professor Guillermo Owen (MA)
Assistant Professor Michael Ross (AA)
Assistant Professor Sandra Scrivener (AA)
Instructor Randy Wight (SP)
Commander Robert Young, USN (37)

SPACE SYSTEMS

Spacecraft Technology

SMALL SATELLITE DESIGN STUDIES (PANSAT)

Directed by Professor Rudolf Panholzer, the Small Satellite Design Studies Program is part of the Spacecraft Technology research effort incorporating proven and 'leading edge' technology in a hardware project.

The Small Satellite Design Studies originated with the ORION Mini-Satellite Program, a prototype general purpose satellite. The continuing project is PANSAT, which will investigate spread spectrum communication with store-and-dump capability for relaying information digitally.

The goal of the Continuing Small Satellite Design Studies Program is to involve officer students in the design, fabrication and integration of a 150 lb. satellite dedicated to function as a small packet radio communication satellite using spread spectrum techniques.

PANSAT will serve as a quick-reaction, low-cost, direct-sequence spread spectrum packet communication satellite, and will provide a low-cost space-based platform for small experiments.

Since spread spectrum modulation provides low-probability-of-detection and low-susceptibility-to-jamming, PANSAT-like technology will be effective in augmenting existing defense communication in times of crisis.

SMALL SATELLITE CONCEPTUAL DESIGN

Professor K.T. Alfriend, Navy TENCAP Space Chair, developed a concept of operations and conceptual design of a satellite for a specific mission. The remainder of the details are classified.

A STUDY OF TRANSIENTS ON A SMALL SATELLITE POWER BUS

To ensure mission integrity of a small satellite, Professor Robert Ashton directed research on a thorough analysis of transients on the unregulated electrical subsystem power bus of PANSAT. This analysis was done via simulation and confirmed by using hardware, including solar panels, filters, dc-to-dc converter and loads.

SMALL SATELLITE THERMAL MODELING

Professor B. Leonard, Naval Space Systems Academic Chair, directed research on thermal modeling and analysis of PANSAT. The scientific objective of this research was to determine the temperature profile of a small satellite.

SMALL SATELLITE CRITICAL FAILURE MODELING

Professor B. Leonard also directed research on a critical failure mode analysis of PANSAT. The objective was to provide NASA with a well researched preliminary system reliability and safety report of the satellite.

Satellite Communications

PANSAT COMMUNICATIONS SYSTEM DESIGN

Under Professor Randy Borchardt's guidance, research on the following six tasks were continued: 1) Complete a test bed for the RF front end with a new design that lowers the power requirements; 2) Complete testing of the Temperature Sensor Multiplexer (TMUX); 3) Complete adaptation of the direct sequence spread spectrum modulator/demodulator Paramax PA100 chip for use with PANSAT; 4) Continue development of the ground station; 5) Continue exploration

of the PA100 chip for follow-on designs and use with other satellites currently in orbit; and 6) Complete development of a channel simulator to assist in accounting for various signal losses and noises encountered in the channel.

Remote Sensing

REMOTE SENSING OF TRACE GASES

Professor David Cleary continued research in the area of remote sensing of the ionosphere. The goal of this project was to develop a passive technique for remote sensing the ionospheric electron density profile on a global basis. The scientific goal was to determine if the electron density can be inferred from the ultraviolet signature of the positive ions in the ionosphere.

During 1995, significant progress was made on the development of a new technique for remote sensing of trace gases. The most notable progress was made on the development of the NPS All-Reflection Michelson interferometer. In addition to instrument development, an analysis of the O^+834-Å emission was conducted to determine the feasibility of its use in ionospheric remote sensing. It was found that for nearly all altitudes this emission is sufficiently bright for this application. (See Dept. of Physics.)

Space Warfare

SYSTEM CONCEPT OF OPERATIONS

Professor K.T. Alfriend, Navy TENCAP Chair, developed a concept of operations for a system providing tactical support for the warfighter. The remainder of the details are classified.

AIR DEFENSE SYSTEM INTEGRATOR AND MULTI-SOURCE TACTICAL SYSTEM ANALYSIS

Professor I. Michael Ross continued his analysis of the Air Defense System Integrator (ADSI) and the Multi-Source Tactical System (MSTS).

ADSI correlates national systems data, airborne and combined service data with ground based radars to support the warfighter.

MSTS allows the warfighter to overlay current national and tactical intelligence data onto multiple types of maps and images thereby enhancing an aircrew's situational awareness. (See Dept. of Aeronautics and Astronautics)

Computer Memory Technology in Space

THIN-FILM FERROELECTRIC TECHNOLOGY (FERRO NPS-001)

Professor Panholzer's team continued support of a Computer Memory Technology in Space project designed to evaluate ferroelectric technology for its suitability in military and space applications.

FERRO NPS-001 was launched on 8 August 1994 and operated until 8 August 1995. Operation support was provided in 1995. Data analysis is planned for 1996-97.

SPACE SYSTEMS

Spacecraft and Flight Hardware Laboratories/Facilities

NPS SPACE FACILITIES AND LABORATORIES

Since 1989, the Space Systems Academic Group (SSAG) and participating departments have dedicated both labor and material resources to the development of several space systems laboratories and facilities designed to satisfy the requirements of the Naval Postgraduate School Space Systems Research Program.

An infrastructure of facilities and support personnel has been developed to promote the successful completion of the PANSAT project. Most of the laboratories required for space research and development at the Naval Postgraduate School are now either fully functional or at a very high level of development.

Under the direction of Professor Panholzer, Program Manager and Group Chairman, the following research laboratories and facilities are being developed to satisfy the requirements of the Naval Postgraduate School Space Systems Research Program:

(SP01) Spacecraft Integration & Test Laboratory (SP)
(SP02) Open Site EMI/EMC Facility (SP)
(SP03) Satellite Ground Station Facility (SP)
(SP04) AIS Computing Facility (SP)
(SP05) Precision Fabrication Facility (SP)
(AA17) FLTSATCOM Satellite Operation, Simulation & Test Laboratory (SP/AA)
(AA18) Spacecraft Attitude Dynamics & Control Laboratory (SP/AA)
(AA19) Spacecraft Environmental Simulation & Test Laboratory (SP/AA)

FY95 REIMBURSABLE PROGRAM
Space Systems Academic Group

K Dollars

[Line graph showing K Dollars (y-axis from 0 to 2,000) versus months OCT through SEP (x-axis) with three plotted series: FY93 AVAILABLE, FY94 AVAILABLE, and FY95 AVAIL]

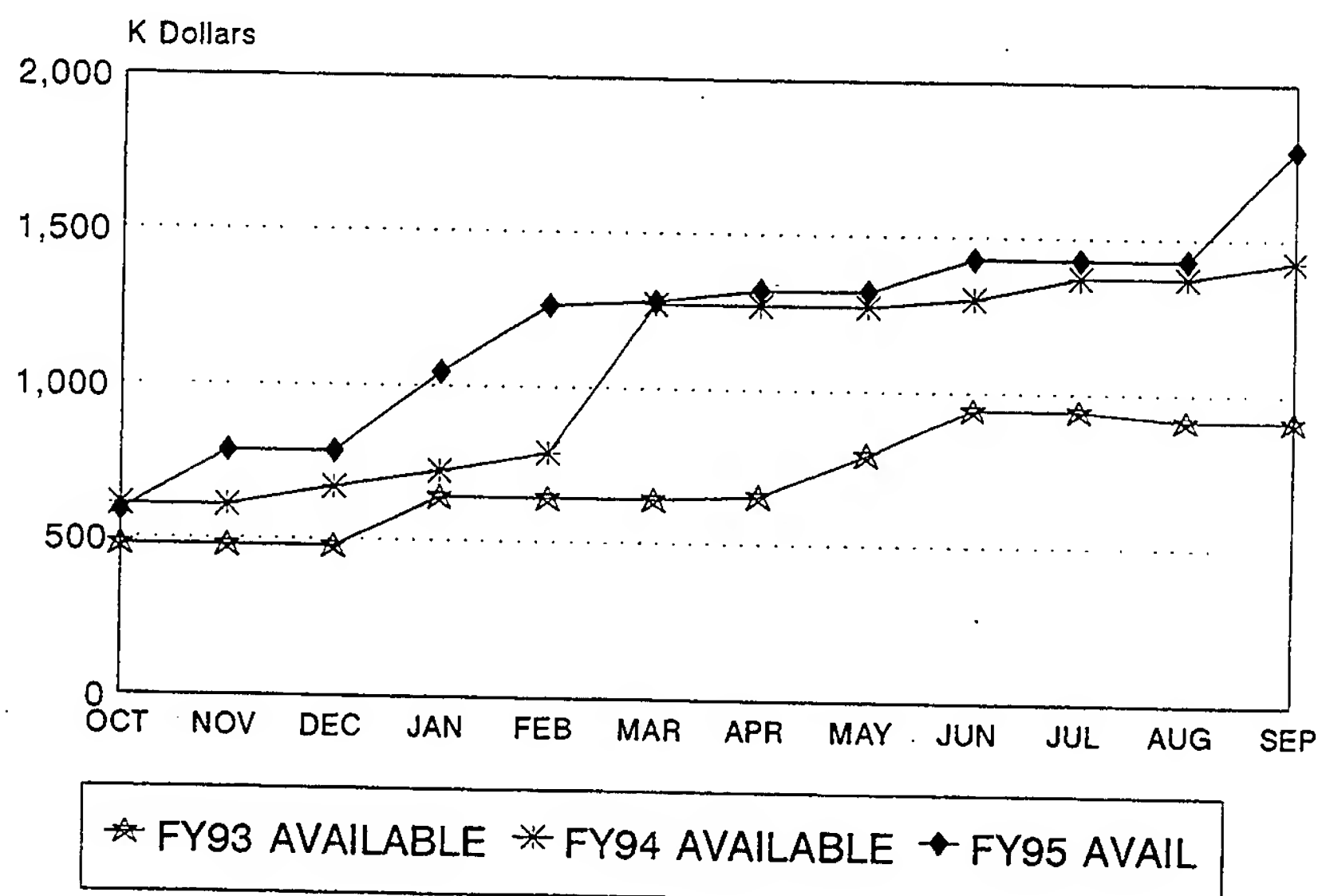⭐ FY93 AVAILABLE ✳ FY94 AVAILABLE ◆ FY95 AVAIL

Figure 1. Reimbursable Funds Available by Fiscal Year.
This graph shows the amount of reimbursable funding available to the department. Dollar amounts include research and academic reimbursable activities.
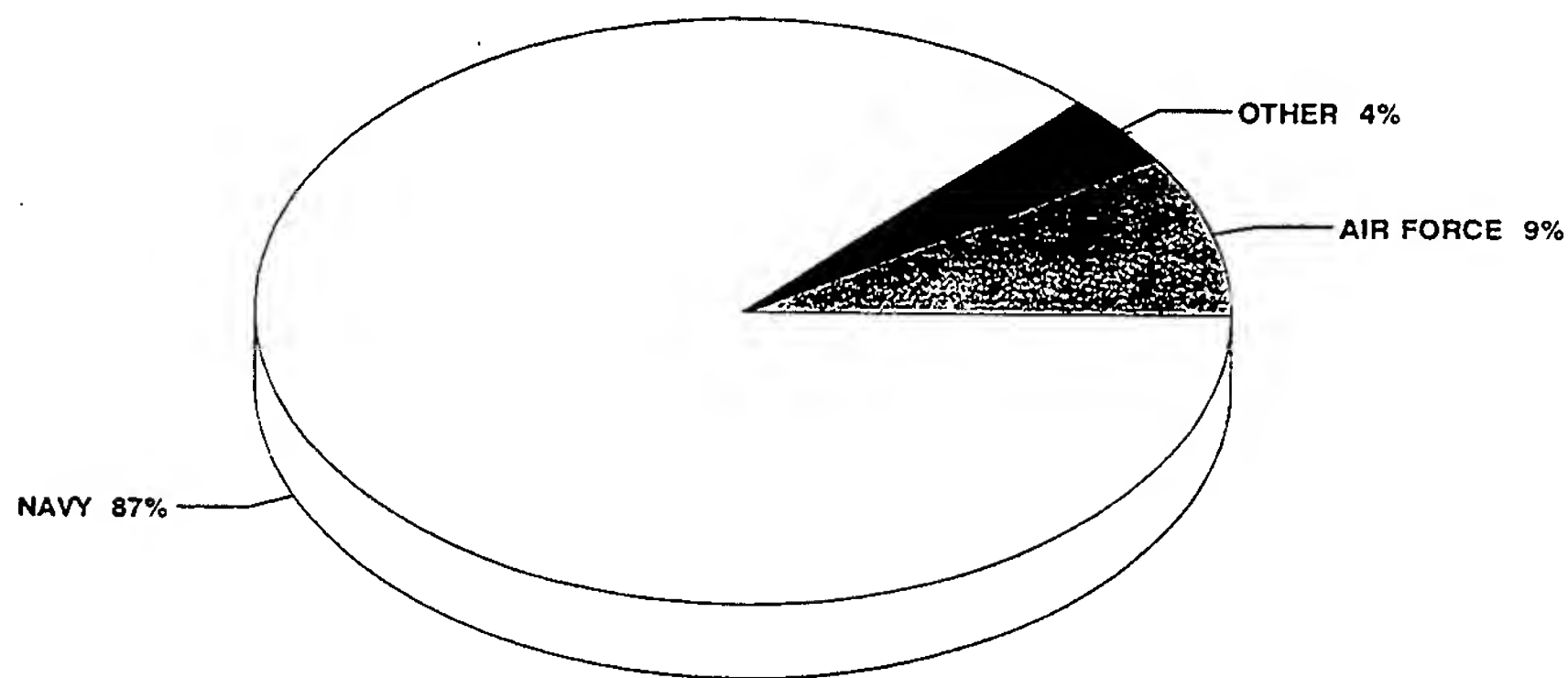
[Pie chart showing FY95 Reimbursable Sponsor Profile]

OTHER 4%

AIR FORCE 9%

NAVY 87%

Figure 2. FY95 Reimbursable Sponsor Profile.

SPACE SYSTEMS

SMALL SATELLITE DESIGN STUDIES (PANSAT)
Rudolf Panholzer, Professor and Chairman
Space Systems Academic Group
Sponsors: Naval Research Laboratory and Naval Postgraduate School

OBJECTIVE: PANSAT is a small satellite configured for launch as a Shuttle secondary payload via the Hitch Hiker program. PANSAT is a 150 pound, digital communications satellite that will offer store-and-forward message relaying using direct sequence spread spectrum modulation. It will operate at a center frequency of 436.5 MHz with approximately 2.5 MHz bandwidth in the amateur radio frequency band. Four megabytes of storage will be available for message relay and telemetry.

SUMMARY: A Memorandum of Agreement (MOA) was signed in 1994 between the US Air Force Space and Missile Systems Center, Space Test and Small Launch Vehicle Programs Office (SMC/CUL) and the Naval Postgraduate School (NPS) for the integration, launch, and space flight of NPS-901, PANSAT, on a Hitchhiker carrier on the Space Shuttle.

A number of administrative milestones were met in the 1995 year, including definition of required documentation and engineering drawings, development of test plans, and initial filing of documents with NASA and the FCC. Specific progress on the PANSAT subsystems follows:

(i.) <u>Spacecraft Structures</u>. Flight structures were fabricated for equipment plates; triangle plates (antenna attachment, handling fixtures/mounts, spacecraft test probe interface); housing for electronics; and Launch Vehicle Interface (LVI).

(ii.) <u>Electric power subsystem (EPS)</u>. The tasks accomplished in 1995 include NiCd battery design and analysis; simulation and hardware implementation; and thorough preflight reliability and stability testing. The power budget for the spacecraft was recalculated utilizing the inputs from the other electronic subsystems. A design was developed which will utilize solar cells, two Nickel-Cadmium batteries, a battery charge regulator, and power conditioning to provide unregulated power from the spacecraft power bus.

Several studies of great importance to mission integrity were also performed. One is a thorough analysis of transients on the unregulated bus due to various subsystem connections. This study was done in order to assure that the power is not interrupted on the output side of any dc-to-dc converter already on the bus. The analysis was done via simulation and confirmed using hardware. In addition, a stability study was performed to assure that the negative resistance characteristic on the various converters does not create oscillations on the bus.

(iii). Development of the <u>Digital Control Subsystem (DCS)</u> continued in 1995 with the design, development, and verification of the error-detection-and-correction (EDAC) memory, mass storage memory modules, and temperature sensor multiplexer modules. Control algorithms were developed utilizing a computer-based experiment controller for the temperature sensor multiplexer and mass storage modules. These two modules were then integrated with the EPS prototype to verify power switching and control interfaces.

Additional work continued in software development and mission operations. Flow diagrams, with defined decision nodes, were developed for the startup procedure of the spacecraft. This decision matrix and logic will eventually be coded and embedded in the flight processor's read-only memory.

(iv.) The <u>Communications (COMM) Payload</u> made incremental gains in the development of prototype hardware. Development hardware and software was purchased to support design of the COMM payload. A final design of the spread spectrum modem is expected by early 1996, when a working prototype will be interfaced with the digital control subsystem. System integrated developmental tests will then be performed for defining control algorithms and mission operations. A second iteration of the antenna radio frequency propagation analysis was also performed detailing design options available for PANSAT.

(v.) The PANSAT Ground Station is now fully capable of communicating with existing amateur radio satellites and is continually and consistently performing message relay with three of the amateur satellites. Furthermore, the ground station has been tied to a World-Wide-Web server allowing individuals a means of retrieving down-linked telemetry via the internet. Documentation concerning the ground station, and the PANSAT project as a whole, is available through the World-Wide-Web medium.

PUBLICATIONS:

Bible, S.R., LT, USN, "The World Wide Web Amateur Satellite Ground Station," a paper presented at The Radio Amateur Satellite (AMSAT) Corporation's 1995 Annual Meeting and Space Symposium, Orlando, FL, 6-8 October 1995.

Bible, S.R., LT, USN, "The World Wide Web Amateur Satellite Ground Station," N7HPR, The AMSAT Journal, Vol. 18, No. 3, p. 9, May/June 1995.

THESES DIRECTED:

Alldridge, D., LT, USN, "Critical Failure Mode Analysis of the Petite Amateur Navy Satellite (PANSAT)," Master's Thesis, September 1995.

Bartschat, J., German Air Force Officer, "Design and Implementation of the PANSAT Software Ground Station," Master's Thesis, September 1995.

Bible, S., LT, USN, "Design And Implementation of a World Wide Web Amateur Satellite Ground Station Gateway," Master's Thesis, September 1995.

Davinic, N., US Civilian, "Evaluation of the Thermal Control System of the Petite Amateur Navy Satellite (PANSAT)," Master's Thesis, September 1995.

Dawson, D., LT, USN, "The Design of a Direct Sequence Spread Spectrum Code Division Multiple Access Environment [for PANSAT]," Master's Thesis, September 1995.

Eagle, P.A., LT, USN, "The Design of an Amateur Radio Interface for Modulation and Demodulation of Petite Amateur Navy Satellite (PANSAT) Communications," Master's Thesis, June 1995.

Gericke, O., German Army Officer, "Design and Analysis of the Housing of the Communication Payload of the Petite Amateur Navy Satellite (PANSAT)," Master's Thesis, September 1995.

Hengst, M., German Navy Officer, "Development of a Computer-Controlled Instrumentation for a Thermal Vacuum Chamber," Master's Thesis, September 1995.

Karapinar, E., LCDR, Turkey Armed Forces, "Modification and Verification of an Antenna Design for the Petite Amateur Navy Satellite (PANSAT) Using the Numerical Electromagnetics Code (NEC)," Master's Thesis, June 1995.

Nichols, T., LT, USN, "A Description of the PANSAT Command Language," Master's Thesis, September 1995.

Oechsel, C., LT, USN, "Implementation of Error Detection and Correction (EDAC) IN the Static Random Access Memory Aboard the Petite Amateur Navy Satellite (PANSAT)," Master's Thesis.

Severson, F., LT, USN, "An Overview of the Petite Amateur Navy Satellite (PANSAT) Project," Master's Thesis, September 1995.

Tackett, S., LT, USN, "Design and [Structural] Analysis of EPS Housing and Circuit Boards for PANSAT," Master's Thesis, June 1995.

Wolfe, S., LT, USN, "Small Satellite Attitude Control for Sun-Oriented Operations Utilizing a Momentum Bias with Magnetic Actuators," Master's Thesis, March 1995.

OTHER:

Professor Panholzer directed the quarterly effort of publishing a newsletter, Ferroelectricity Newsletter, on ferroelectricity research, to provide information on national and international symposia, conferences, workshops, and meetings in the field of ferroelectricity.

DOD KEY TECHNOLOGY AREAS: Electronics, Human System Interface, Computing and Software

KEYWORDS: PANSAT, Petite Amateur Navy Satellite, Small Satellites Design Program, Spread Spectrum

THIN-FILM FERROELECTRIC EXPERIMENT (FERRO NPS-001)
Rudolf Panholzer, Professor and Chairman
Space Systems Academic Group
Sponsors: Naval Research Laboratory and Naval Postgraduate School

OBJECTIVE: The NPS research program on Computer Memory Technology in Space has as its objectives: (i) to enhance the education of officer students in the Space Systems Curricula, (ii) to provide a cost-efficient experiment to test the space-related characteristics of ferroelectric capacitors and other devices, and (iii) to contribute to the military efforts to evaluate ferroelectric materials.

The Thin-Film Ferroelectric Experiment (FERRO NPS-001) is the current continuing project of the Computer Memory Technology in Space Research Program. The goal of this project is to evaluate ferroelectric technology to determine its suitability in military and space memory applications.

SUMMARY: The inherent radiation tolerance, switching speed and potential memory density (greater than current RAM technologies) make ferroelectric material a potential component in future radiation hardened RAM. However, it is not fully understood how the aging and fatiguing properties of this material will be affected by exposure to the rigorous space environment. Additional knowledge gained from this research will facilitate the decision process to replace present nonvolatile memory technology with ferroelectric RAM in a high radiation environment.

In FY92-93, a new experiment, named "FERRO NPS-001," was designed to fly aboard the Advanced Photovoltaic and Electronics Experiments (APEX) mission. It tested the effects of space environment (most importantly radiation) on aging and fatiguing characteristics of ferroelectric capacitors.

FERRO NPS-001 was designed to gather data to resolve some of these unknown material properties. It was launched on Aug 8, 1994 aboard the Pegasus launch vehicle and operated until Aug 8, 1995.

During the 1995 calendar year, support was provided for system tests performed by Orbital Science Corp.; support for training activities was provided to the Command Space Test Center (CSTC) as it relates to operating the Ferro (NPS-001) experiment; and developmental work continued on software to process orbital data tapes. In 1996-97, data/telemetry from the experiment will be analyzed.

Once thin-film capacitors have shown that they are rugged enough to operate in space, the experiment will switch to testing non-fatiguable ferroelectric memory devices.

SPACE SYSTEMS

DOD KEY TECHNOLOGY AREAS: Electronics, Materials, Processes and Structures

KEYWORDS: Ferroelectric capacitors, nonvolatile memory, APEX mission

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ACADEMIC GROUP

UNDERSEA WARFARE

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UNDERSEA WARFARE

The Undersea Warfare Academic Group (USWAG) consists of twelve (12) faculty members plus the Curricular Officer. The faculty members teach in the USW curriculum and are responsible for its academic content. Members conduct USW-related research and serve as thesis advisors for USW students.

Associate Professor Steve Baker (PH)
Visiting Professor Al Bottoms (UW)
Professor Robert Bourke (OC)
Assistant Professor Donald Brutzman (UW)
Associate Professor Ching-Sang Chiu (OC)
Professor James Eagle (OR), Chairman
Associate Professor Ralph Hippenstiel (EC)
Assistant Professor Robert Keolian (PH)
Associate Professor James Sanders (PH)
Associate Professor Clyde Scandrett (MA)
Assistant Professor Kevin Smith (PH)
Professor Alan Washburn (OR)
CDR Bob Young (37), Curriculum Officer

An overview of research sponsored by the USWAG is below.

Middle Atlantic Bight Field Study

Professors Ching-Sang Chiu and Kevin Smith collaborated with Woods Hole Oceanographic Institution in the Office of Naval Research sponsored Middle Atlantic Bight Field Study. The overall goal is to understand the propagation of sound from the continental slope to the continental shelf, including the effects of shelf-break frontal features and seasonal stratification.

Active Acoustic Transient Localization

Professors Kevin Smith and Ching-Sang Chiu investigated the influence of the physics mismatch due to less-than-ideal acoustic ray model predictions on the localization of full-wave signals. The eventual research goal is to develop effective and accurate methods for passive transient localization.

Barents Sea Tomography

Professors Ching-Sang Chiu, James Miller and Robert Bourke continued the analysis of data obtained in the 1992 Barents Sea Polar Front Experiment.

Ocean Variability

Professors Ching-Sang Chiu, James Miller and A.J. Semtner studied the variability and stability of cross-basin acoustic arrivals using Hamiltonian ray tracing for selected source-receiver sites through various Semtner-Chervin global ocean model outputs.

Multicast Backbone (Mbone)

Professor Brutzman configured a local area network at the Naval Undersea Warfare Center (NUWC) Newport to support real-time audio and video. Also demonstrated was the use of multicast audio/video services in support of the New Attack Submarine Open System Critical Item Test.

CAVES Noise Cancellation

Professor Robert Keolian and LCDR Daphne Kapolka developed a correlated noise cancellation technique for the CAVES fiber optic flank array. The output of noise sensors placed near internal noise sources are correlated with the output of the CAVES sensors to obtain running average transfer functions between the noise sources and the array. These accumulated transfer functions and the instantaneous noise signals are used to subtract the self-noise appearing in the CAVES sensors.

Mine Countermeasures Program

Professor Don Walters investigated methods for the identification and classification of mine-like objects using adaptive acoustic imaging plus synthetic and inverse synthetic aperture sonars techniques. Professor Al Bottoms provided overall coordination of mine warfare-related activities at NPS. This included planning the weekly Menneken Lecture Series on Mine Warfare and coordinating preparations for a major mine warfare symposium scheduled for November 1996 at NPS.

Shallow Water Bottom Reverberation

Professors Robert Bourke and James Wilson investigated the impact of bottom reverberation and energy spreading loss on AN/SQS-53C performance in shallow water.

FY95 REIMBURSABLE PROGRAM
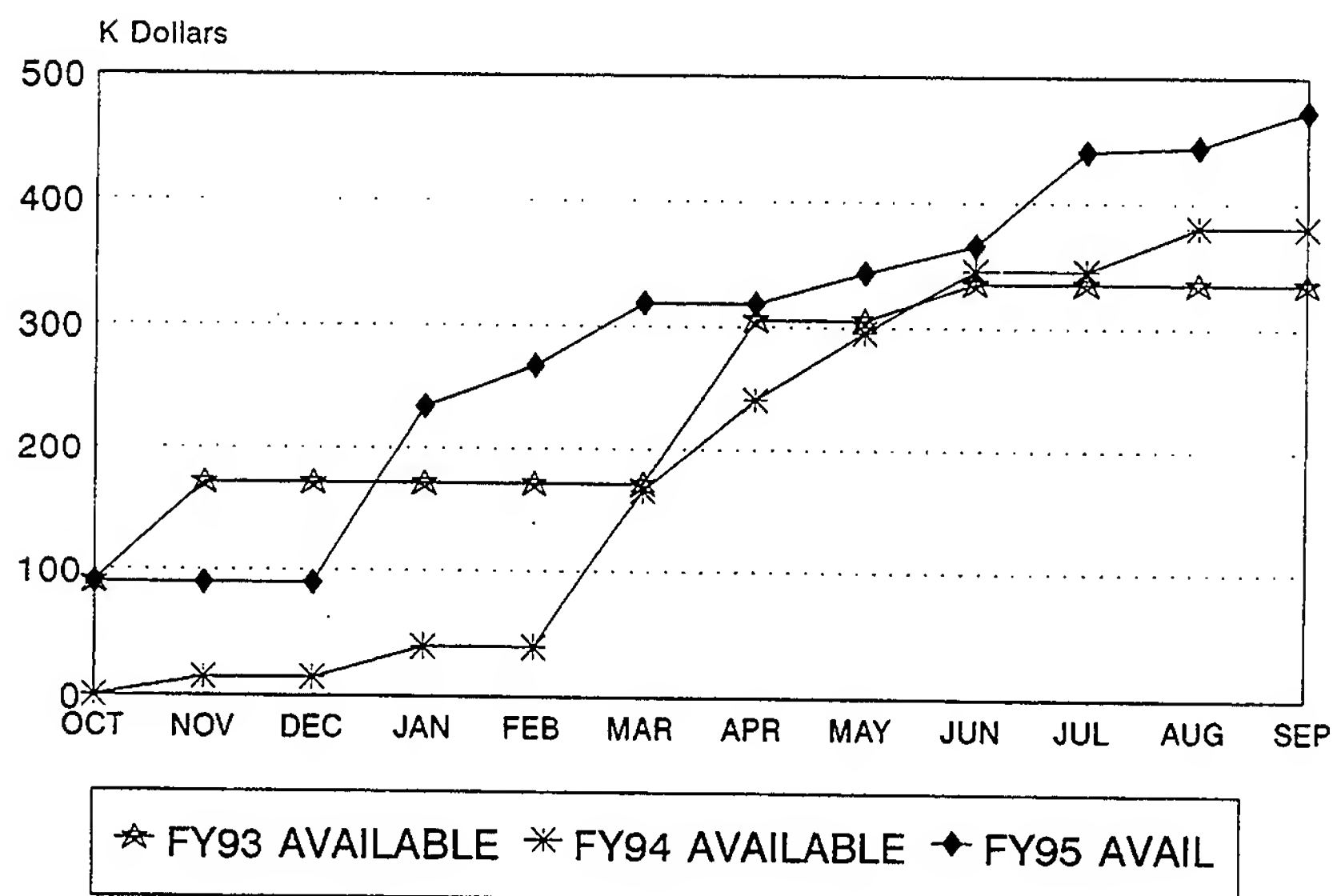## Undersea Warfare Academic Group

K Dollars

Figure 1. Reimbursable Funds Available by Fiscal Year.
This graph shows the amount of reimbursable funding available to the department. Dollar amounts include research and academic reimbursable activities, as well as funding from Cooperative Research and Development Agreements.
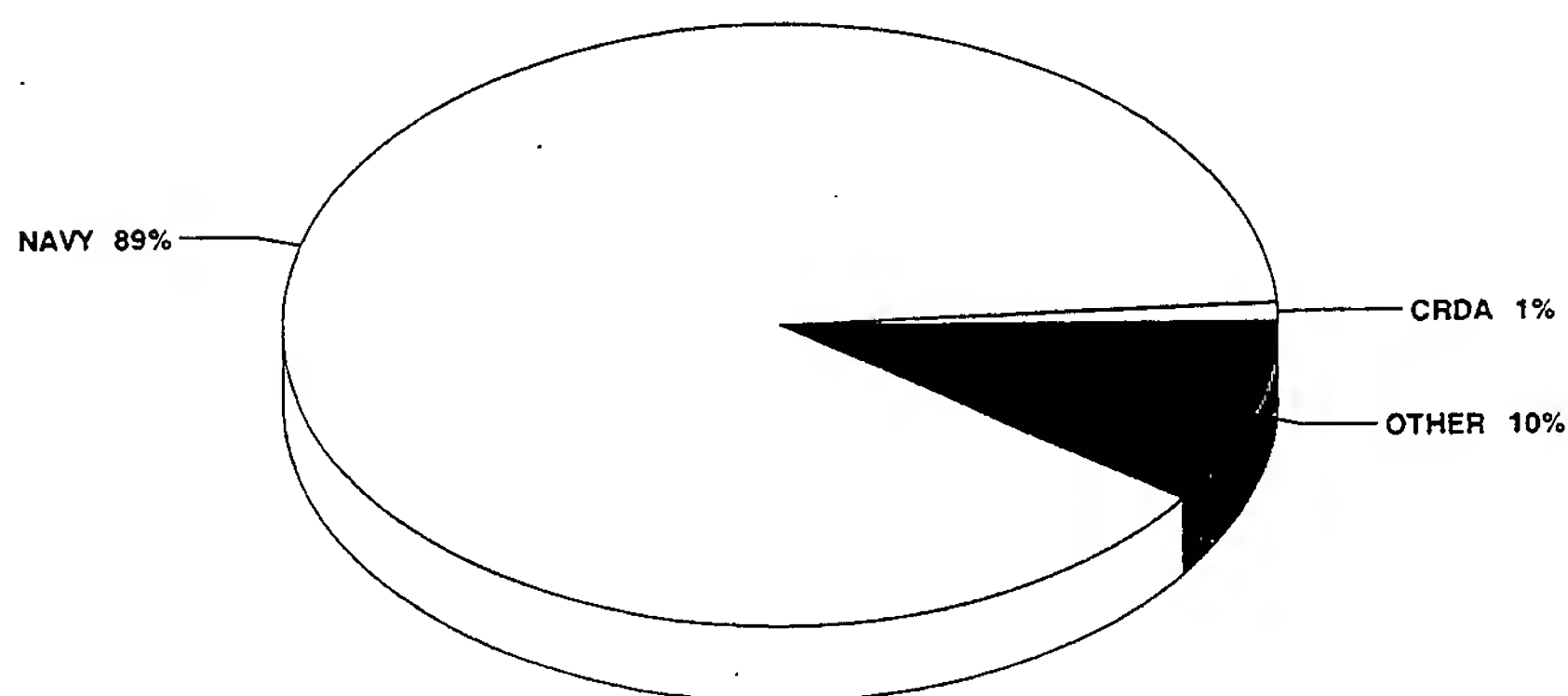

Figure 2. FY95 Reimbursable Sponsor Profile.

41

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    Monterey, CA 93943-5100

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    Naval Postgraduate School
    Monterey, CA 93943-5000

4. Chairman, Code C3   5
    Command, Control & Communications Academic Group
    Naval Postgraduate School
    Monterey, CA 93943-5000

5. Chairman, Code IW   5
    Information Warfare Academic Group
    Naval Postgraduate School
    Monterey, CA 93943-5000

6. Chairman, Code SP   5
    Space Systems Academic Group
    Naval Postgraduate School
    Monterey, CA 93943-5000

7. Chairman, Code UW   5
    Undersea Warfare Academic Group
    Naval Postgraduate School
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